EFFECTIVE ADMINISTRATION OF INHALATIONAL THERAPY WITH SPECIAL REFERENCE TO AMBULATORY AND EMERGENCY OXYGEN TREATMENT*

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The value of the use of oxygen beyond the confines of the hospital by means of portable apparatus has recently been described in reports of the treatment of various syndromes characterized by acute serious hypoxia.[1-6] Although the importance of following effective standards of inhalational therapy was stressed in these reports, portable oxygen apparatus has, in some instances, been promoted commercially without providing adequate information on such vital characteristics as the flow rate of oxygen delivered from the cylinder.

The intention of this presentation is to outline the requirements for effective administration of oxygen with special reference to their application in ambulatory or emergency therapy.

The first "Standards of Effective Administration of Inhalational Therapy" were formulated by the Committee on Public Health Relations of The New York Academy of Medicine in 1943.[7] In 1948 and 1950 the principles of oxygen administration were reviewed because the knowledge of physiologically-based therapy had been extended and improved apparatus had been developed.[8, 9] It is appropriate at this time to emphasize the importance of observing already accepted standards in the everyday practice of ambulatory and emergency inhalational therapy, either by the physician carrying oxygen in his satchel or by the patient who has been instructed to administer oxygen to himself.

Two general statements may be made: 1) When continuous administration of oxygen is employed, a reliable two-stage or one-stage regulator is required for safe administration; and 2) there is no justification for return to low-pressure oxygen cylinders. The progressively diminishing flow from low-pressure cylinders provides uneven and ineffective therapy.

When oxygen therapy with portable apparatus is undertaken by the physician in emergency cases of hypoxia, the size of the cylinder must obviously be less

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than that which is commonly used in a hospital. For the sake of portability, lightweight high-pressure cylinders with a capacity of from 75 to 150 liters have been made available with two-stage regulators which have been found capable of maintaining the prescribed flow, from 3 to 10 liters per minute, for example, for the duration of their use. Larger cylinders may be employed when the physician's car is utilized to store the apparatus. However, an ambulatory device that weighs more than 5 or 6 pounds is burdensome to carry on house visits.

For the group of patients with chronic pulmonary disease who employ oxygen on an ambulatory basis, as in an exercise training program, the apparatus, together with the nasal cannula and the connecting tubing, should not weigh more than from 3 to 5 pounds, including the weight of the regulator. Cylinders of this type, when equipped with a refilling device that has a very small orifice and a wire connection between the small tank and a large one, offer patients with respiratory and cardiac disease an econom:cal method of oxygen inhalation. In connecting a large 244 cu. ft. cylinder to a small cylinder with a capacity of from 75 to 150 liters, equipped with a check-valve that closes when the cylinder has been filled, it is important that the maximal area of the orifice beyond the check valve be 0.003 sq. in. If the connection has a large bore, an accidental break will result in a sudden escape of oxygen and a violent projectile movement of the cylinder.

The various precautions which have been described in books and manuals on the employment of oxygen should, of course, be followed by the physician, the patient, and the technician, all of whom play a part in the procedure. These instructions include the following:

1. Avoid contact of oil or oily hands with the oxygen cylinder, regulator or refilling device.
2. Prevent dust from entering regulator; open large tank to blow out any dirt that may be present before attaching regulator or refilling device. Close refilling orifice of small cylinder with nut attachment when not in use.
3. The check-valve in the small cylinder should close when disconnected.
4. The filling device should preferably be equipped with a diaphragm valve at its attachment to the large (244 cu. ft.) tank; under these circumstances the flow of oxygen would automatically cease when a flow rate exceeding 15 liters per minute was reached. With this additional safety feature there would be no significant escape of oxygen from either the large or the small cylinder, if a break in the connection should occur. (It also appears to be desirable to have an automatic safety valve of this type attached to any large oxygen cylinder in use at a place where the cylinder might fall and break off the regulator.)

In order to utilize the contents of a large cylinder that is partially full, the small apparatus may first be attached to it for partial filling and then topped off from a full cylinder in order to obtain the proper pressure, i.e., from 1500 to 2000 pounds per square inch.

When oxygen is administered continuously into a mask, some means must be used to prevent the rebreathing of expired air, as cautioned in the previous standards, unless high flows of oxygen are used to wash out the expired carbon dioxide, namely, more than 4 liters per minute, and preferably more than 6 liters per minute.* Since at the present time virtually all oxygen masks used for the administration of oxygen in hospitals are equipped with inspiratory valves which prevent rebreathing, it would appear desirable to have disposable masks similarly equipped. With the use of plastic bag-like masks which contain perforations for dilution of the oxygen with inspired air and for the elimination of expired air, the flow rate of oxygen from the cylinder should be high enough to keep the carbon dioxide in the mask below one per cent.

In the use of mask apparatus which permits partial rebreathing, it has been shown that oxygen flows of less than 4 liters per minute result in concentrations of between 1 per cent and 2 per cent of carbon dioxide in the inspired air.[5-11] Although the smaller the rebreathing bag or the mask container, the less will be the carbon dioxide accumulation, the volume of the exhaled air potentially stored in the rebreathing-type masks should be recognized as the source of carbon dioxide that will be inhaled in the subsequent inspiration. This factor of carbon dioxide accumulation in the rebreathing type of mask may be a serious hazard when oxygen flows of only 1 or 2 liters per minute are administered.

In patients with diffuse obstructive pulmonary emphysema, low flow rates of oxygen administered by nasal catheter are sometimes utilized at the start of the treatment, in order to permit an adaptive reaction by which base is retained in the blood, and thereby to avoid an acid shift in pH. The treatment of serious hypoxia in other clinical entities, however, requires higher flow rates at all times, irrespective of the device employed. With portable non-rebreathing apparatus in which the oxygen is stored in the inspiratory bag during expiration, rates of flow from 3 to 5 liters of oxygen per minute may provide sufficiently high concentrations in the inspired air to relieve or to diminish hypoxia.

With portable apparatus the actual percentage of oxygen in the inspired air varies with the pulmonary ventilation. In Table I the oxygen concentrations in the inspired air are shown at varying minute volumes of respiration. These concentrations may be attained, provided a collecting reservoir bag is used, with an inspiratory valve to prevent rebreathing, and also provided that the total amount of oxygen includes that administered throughout the respiratory cycle. Inasmuch as short-of-breath patients breathe in excess of basal pulmonary ventilation rates, i.e., above 6 and usually above 8 liters per minute, the estimated oxygen enrichment of the atmosphere should generally be evaluated at ventilations between 10 and 16 liters per minute. The oxygen concentration of the inspired air at a flow rate of 5 liters per minute would be 60 and 46 per cent at pulmonary ventilations of 10 and 16

* The determination of the alveolar carbon dioxide tension to test the elimination of carbon dioxide has no bearing on the suitability of oxygen mask apparatus, since, as shown by Haldane and Priestley,[12] an increased pulmonary ventilation tends to keep the alveolar carbon dioxide tension constant as the inspired carbon dioxide is elevated; thus, inhalation of 1 per cent and 2 per cent carbon dioxide may result in a rise in pulmonary ventilation of 20 per cent and 40 per cent respectively,[10] with practically no change in alveolar carbon dioxide tension.

TABLE I—OXYGEN CONCENTRATION OF INSPIRED AIR AS AFFECTED BY OXYGEN FLOW RATE, PULMONARY VENTILATION OF INDIVIDUAL PATIENT, AND TECHNIQUE OF ADMINISTRATION

OXYGEN FLOW RATE IN LITERS PER MINUTE		*Pulmonary Ventilation Liters Per Minute*					
Continuous flow into non-rebreathing collecting bag of nasal or mask device	Administration during inspiration, flow stopped in expiration. Flow rate below is that during inspiraton only	6	8	10	12	16	20
		Oxygen Concentration Inspired Air Per Cent					
1	2	34	31	29	28	26	25
2	4	47	41	37	34	31	28
3	6	61	51	45	41	36	33
4	8	77	61	53	47	41	37
5	10	87	70	60	54	46	41

The flow rate with inhalation of oxygen during inspiration only is twice that of continuous administration, but the total volume of oxygen inspired is the same in these two cases. In administration by nasal cannula in which oxygen is lost during expiration, the volume of oxygen required to obtain similar oxygen percentages in the inspired air is two to three times higher, depending on the length of expiration.

The pulmonary ventilations of the ambulatory or dyspneic patient are frequently in the range of from 10 to 16 liters per minute, at which rates 3 liters of oxygen per minute will provide between 45% and 36% oxygen, and 4 liters between 53% and 41% oxygen in the inspired air, provided that the oxygen delivered during expiration is utilized in the subsequent inspiration. When expiration is prolonged to occupy two-thirds of the cycle, as in severe asthma and emphysema, considerable oxygen is wasted with the use of a nasal cannula without a reservoir bag. Thus, continuous administration of 3 liters per minute would provide 1 liter of oxygen during inspiration, since nasal oxygen is inspired during one-third of the respiratory cycle. At a ventilation of 16 liters per minute, the concentration would be 26%, the same as that listed above with a continuous flow of 1 liter per minute into a collecting bag, or with a flow rate of 2 liters per minute in cases in which inspiration and expiration are equal in duration, and oxygen is inhaled in inspiration only.

liters per minute, provided the total volume of 5 liters is collected in a non-rebreathing mask and inhaled during inspiration. In cases with more severe dyspnea, represented by a pulmonary ventilation of 20 liters per minute, the percentage of inspired oxygen would be 41.

When the nasal cannula is employed without a reservoir bag, and the patient happens to be one with a prolonged expiration, the oxygen enrichment of the atmosphere may be only one third of that which is provided by an apparatus in which the total oxygen flow is utilized for inspiration (see Table I). Since the nasal cannula is more comfortable than a mask, the recent introduction of a cannula-type apparatus with two 300 cc. non-rebreathing plastic bags serves a useful purpose in providing comfortable, effective and economical oxygen therapy.[6]

Use of disposable cylinders at a pressure of 400 pounds per square inch with a fixed-orifice type of regulator is a retreat to a method of administering oxygen that is extremely costly; in the case of cylinders containing 25 to 26 liters of oxygen it also results in flow rates that fall from 5.5 to 2 liters per minute or less at the end of 5 minutes, and to 1 liter per minute or less at the end of 8 minutes, ultimately dropping below the actual oxygen consumption of the adult individual.[6, 13] It is evident that inhalation of oxygen through a mask in which these low flow rates are employed is inadvisable. The hazard of ineffective treatment in the case of a patient seriously ill is obvious.

When oxygen is inhaled only during inspiration, either through the nose or through a mouthpiece without a rebreathing bag, the hazard of carbon dioxide accumulation is not present. However, it should be recognized that a continuous flow rate of 4 liters per minute would provide 2 liters or less during inspiration. In Table I the concentration of oxygen is calculated under conditions in which oxygen is provided during inspiration only; in some types of portable dispensers the oxygen is turned on during inspiration only and the actual concentration inhaled is then dependent upon the flow rate as well as the minute volume of respiration. Thus, if 2 liters per minute are inhaled during inspiration, the actual flow rate being 4 liters per minute and inspiration and expiration being equal in duration, the concentration of the inspired oxygen can be estimated from the Table, with the understanding that the minute volume of the patient can itself be estimated. However, in patients with a prolonged expiration, a continuous flow of 4 liters per minute through a nasal cannula may provide only 1.3 liters of oxygen to the inspired air.

It is necessary, therefore, to warn against the use of devices in which the flow rate cannot be regulated. From the considerations reviewed here, it is clear that the volume of oxygen in a cylinder and the rate of flow provided by the device used should be known. If a low-pressure container delivers approximately 25 liters of oxygen before it is empty, it is highly misleading to advertise the device for emergency treatment either for 15 minutes of continuous administration into a mask, or for 25 minutes of intermittent flow into the mouth.

It is beyond the scope of this statement to appraise the value of specific types of portable apparatus designed for use by physicians, nurses, technicians and patients in the treatment of hypoxia, particularly as it occurs in cardiac and respiratory disease. The present review is intended to reinforce the importance of conforming to the standards of effective administration of inhalational therapy as set forth in 1950,[9] whatever method is used. Although recent experience has brought out the value of ambulatory oxygen therapy, greater emphasis must be placed on the maintenance of effective and safe procedures in carrying out this form of treatment for the relief of hypoxia.

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